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Simple Integration of Recycled Cement Sack Fibres into Pervious Concrete for Engineering Applications

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Abstract **-** This study proposes a straightforward methodology for incorporating cellulose fibres (CF) from recycled cement sacks into pervious concrete. The process involves converting the sacks into pulp and preparing the material to achieve the minimum saturation conditions required for integration into the concrete mix. As part of the research, CF was evaluated in the cementitious matrix at three dosages (3.86, 5.79, and 7.73 kg/m³) to assess their effects on rheological behaviour. It was validated in the production and testing of pervious concrete. A simple and accessible mechanical procedure was developed to produce the CF, requiring a minimum pre-saturation period of 12 hours to ensure adequate mix flowability and sufficient paste thickness within the matrix. Saturated CF inclusion improved permeability by up to 33% without compromising mechanical performance, acting as internal curing agents, enhancing long-term compressive strength at selected dosages. CF enhanced matrix–aggregate bonding, improved post-crack integrity, reduced brittleness, and promoted a more ductile failure mode. This approach supports sustainable construction practices by valorising cement packaging waste and offers a practical solution that could be adapted for industrial application, depending on local technological and economic conditions.

***Keywords*:** Pervious concrete, recycled cement sacks, cellulose fibres, sustainable construction, internal curing.

1. Introduction

Pervious concrete contains little or no fine aggregate, with a highly porous and interconnected structure. This facilitates water infiltration, promoting aquifer recharge and reducing surface runoff, contributing to flood prevention [1]. Its capacity to absorb water also helps mitigate the urban heat island effect [2]. However, its use is often restricted due to the brittleness of the binder matrix, which limits mechanical performance under high loads [3].

To address this limitation, fibre reinforcement has been widely explored to enhance the mechanical properties of pervious concrete [4]. Various types of fibres have been studied, including synthetic [5-9], metallic [8, 10-12], carbon [13] and organic fibres [14, 15]. Synthetic fibres such as polypropylene and polyethylene have shown significant improvements in strength [5, 16], although some, like polyester, may reduce permeability [6]. Metallic fibres, while effective in increasing strength, may cause clumping at high dosages and are susceptible to corrosion [10-12]. Carbon fibres can increase strength by up to 40 %, but often reduce permeability [13]. Organic fibres—derived from agricultural waste, recycled paper, cardboard, and cement sacks—have gained attention as sustainable alternatives [17-21], especially considering that paper-based waste accounts for 26% of global landfill content [22], and cement production generates around 2.59 kg of paper waste per tonne, mainly from sacks [23].

These sacks can be incorporated into cementitious materials as strips or as pulp. When used as strips, they tend to be less effective due to their limited dispersion capacity within the matrix [18], leading to weak zones and potential obstruction of drainage channels in pervious concrete. In pulp form, however, the sacks are transformed into cellulose microfibres that disperse more uniformly and interact more effectively with the matrix, improving both rheological and mechanical performance [17, 19, 20], including enhanced tensile and compressive strength in pervious concrete without significantly compromising its permeability [14].

The performance of those cellulose microfibres depends on several factors, such as dosage, curing time, and pre-treatment method employed. Research on cement pastes has shown that the incorporation method significantly influences rheology and hydration. For instance, if the fibres are not pre-saturated, their high absorption capacity undesirably alters the water-to-cement ratio; conversely, fully saturated fibres may delay early hydration, reducing early-age strength, but later contribute to internal curing and microstructural development through gradual water release and nucleation effects [24, 25]. Excessive fibre content can also lead to agglomeration and poor dispersion, negatively affecting workability [17, 18]. In addition, most studies have focused on cementitious pastes, and their application in pervious concrete remains limited.

The present study proposes a straightforward methodology for incorporating cellulose fibres from recycled cement sacks into pervious concrete. The method is first evaluated at the matrix level through rheological and compressive strength testing, and subsequently validated at the concrete level by assessing mechanical and hydraulic performance at 7 and 28 days of curing.

2. Materials and methods

2.1. Materials

Type I Portland cement was used, composed mainly of 61.2% CaO and 20.7% SiO_2. Regarding its physical properties, it exhibits a Blaine specific surface of 3620 cm^2/g, a density of 3.14 g/cm^3, and an initial setting time of 122 minutes. No plasticiser additives were used.

Semi-crushed coarse aggregate, sourced from alluvial deposits of igneous rocks, was used in this study. The particle size distribution was between 1/2" and 3/8" sieves, in a 75:25 ratio, achieving a void ratio of 44 %, under ACI 522 [26]. The material presented a specific surface area of 0.15 m^2/kg and a water absorption capacity of 0.95%, a loose unit weight of 1403.3 kg/m^3, a rodded unit weight of 1539.8 kg/m^3, a specific gravity of 2.77, and a moisture content of 0.63 %.

The waste cement sacks were supplied by a local company specialising in industrial waste management.

2.2. Experimental methodology

The experimental program was developed into four steps, as detailed next: (1) Production of cellulose fibres (CF), (2) evaluation of the CF absorption capacity, (3) preparation and characterisation of the cementitious matrix with CF, and validation in concrete pervious, combining the matrix with coarse aggregates.

a) Production of CF

A mechanical process was developed to extract cellulose fibres from discarded cement sacks, avoiding chemical treatments or specialised equipment. The method was designed to be simple and reproducible, making it suitable for laboratory and field-scale applications.

b) Evaluation of the absorption capacity of CF.

To determine the minimum saturation time required for the fibres to act as internal curing agents, the water absorption of CF was evaluated following the Salem & Al-Salami procedure [19]. The CF sheets were manually dispersed in water and moulded into 15 spheres of 2 cm in diameter. These were oven-dried at 110 °C for 12 hours to reach constant mass. The samples were then immersed in water for various durations (10 seconds to 15 hours), and after each interval, excess water was removed with filter paper before weighing. This was repeated until the weight stabilised.

c) Preparation and characterisation of the cementitious matrix with CF.

The incorporation of CF was first evaluated at the matrix level, observing rheological and compressive strength testing. A mixing process adapted from the conventional cement paste mixing [27] was used to determine the incorporation of CF. CF in pulp form were incorporated into the mixing water at dosages of 0 (control), 3.86, 5.79, and 7.73 kilograms per cubic metre of cementitious matrix, as recommended by ACI Committee 522 [26]. All mixtures were prepared with a water-to-cement ratio of 0.35.

Rheological properties were assessed through flowability, using the flow table test [28], and actual paste thickness (APT), following Xie et al. methodology [29]. APT reflects the ability of the paste to coat aggregates, indirectly indicating adhesion and required volume. It was calculated in millimetres using Equation 1.

$$APT\ (mm) = \frac{M_p}{M_a * \rho_p * S_a} \times 10 \tag{1}$$

Where M_p is the mass of cement paste adhered to the aggregate (g), M_a is the mass of aggregate in SSD condition (g), ρ_p is the paste density (g/cm^3), and S_a is the specific surface area of the aggregate (cm^2/g). The mechanical strength of the matrix was evaluated by compression test on 5 cm cubic specimens at 7 and 28 days [30].

d) Validation of pervious concrete incorporating CF

Once the incorporation conditions were established, pervious concrete was prepared considering a fixed matrix content of 0.233 m³ and 1462.8 kg of coarse aggregate per m³ of concrete.

As shown in Figure 1, materials (cement, water, aggregate, and ambient-dry CF) were weighed separately. CF were dispersed in half of the total mixing water. In the mixer, the aggregate was added first, followed by half of the water (without CF), the cement, and finally the remaining water containing the fibres. Mixing was conducted for 3 minutes, paused for 1 minute to scrape the walls, and resumed for 2 more minutes. The fresh mix was placed in moulds in two layers, compacted with 20 uniform blows of a Proctor hammer per layer. Specimens were demoulded after 24 hours and cured until the designated test ages.

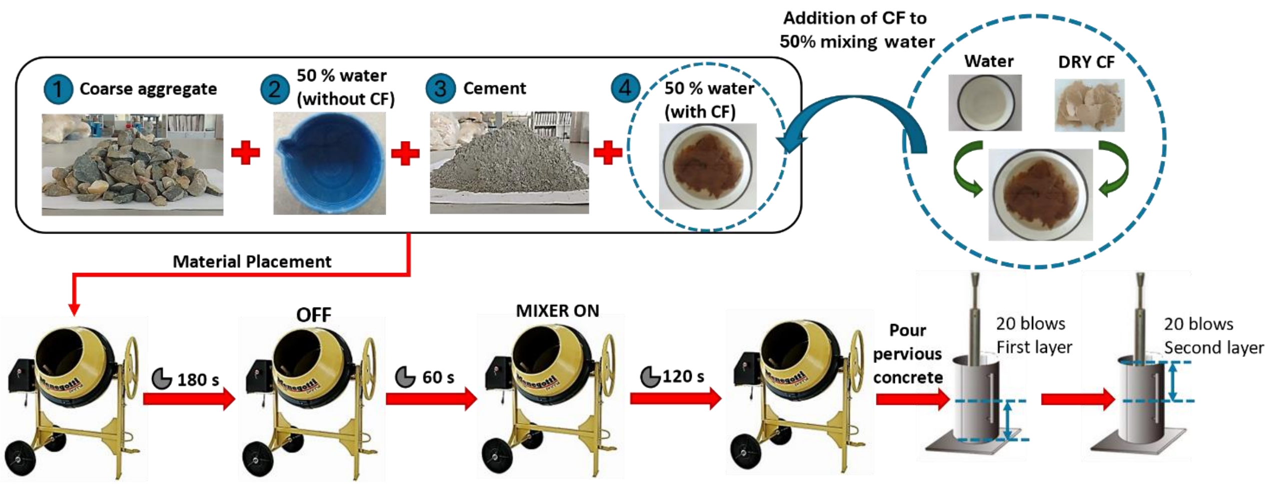

Fig. 1: Process of mixing of pervious concrete.

Permeability was assessed at 7 days using a falling head permeameter, following ACI 522 guidelines [26]. Samples were cast in UHMW tubes (10 cm diameter × 20 cm height), and the coefficient of permeability (K) was calculated using Equation 2.

$$K = \frac{A_1 h}{A_2 t} ln\left(\frac{h_i}{h_f}\right) \tag{2}$$

Where A_1 is the cross-sectional area of acrylic tube (cm^2), A_2 is the cross-sectional area of concrete sample (cm^2), h is the sample length (cm), hi and h_f are the initial and final water level (cm), respectively, and t is the time for water to drain from h_i to h_f (s).

Mechanical performance was evaluated by compression [31] and tensile strength [32] tests on cylinders of 100 mm diameter and 200 mm height, and flexural strength [33] on prismatic beams of 150 × 150 mm cross-section and a length of 500 mm. All tests were conducted at 7 and 28 days.

3. Results and discussion

3.1. Production of CF

Discarded cement sacks were cleaned and cut into approximately 2 × 3 cm fragments. These fragments were soaked in water for 48 hours to soften the cement sacks and then mechanically processed in a 1400-watt blender for 40 minutes to disintegrate the material into a fibrous pulp. The pulp was uniformly spread over a Raschel mesh and air-dried at room temperature for 48 hours. The production process is illustrated in Figure 2. Once dried, the resulting cellulose fibre (CF) sheets were stored until use.

This simple mechanical procedure enabled the consistent extraction of cellulose fibres without the use of chemical treatments or specialised equipment. The process proved effective in producing homogeneous fibres suitable for further incorporation into cementitious matrices for pervious concrete.

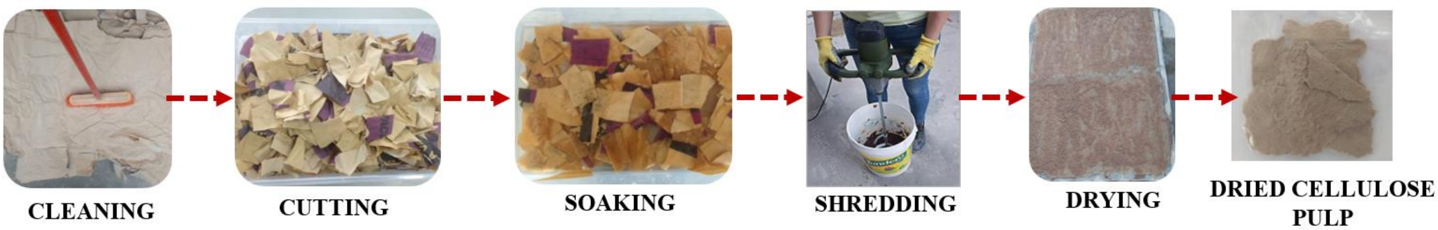

Fig. 2: Schematic of the processing to obtain cellulose fibre (CF).

The extracted CF exhibited a specific gravity of 1.02 [34] and a moisture content of 7.19% [35]. Morphological characterisation by scanning electron microscopy (SEM) revealed free-lignin fibres [22] ranging in length from 2.7 mm to 12.5 mm, and a ribbon-like structure with a ribbed surface along its longitudinal axis (Fig. 3). Based on their dimensions, the CF were classified as microfibres, with thicknesses between 5 and 10 µm and widths between 30 and 60 µm, with average values of 8 µm and 44 µm, respectively, resulting in a form factor greater than 100 [36].

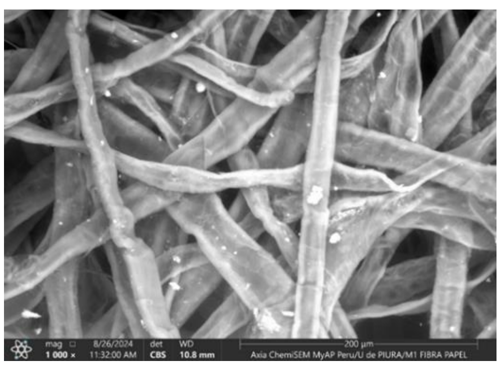

Fig. 3: CF morphology and texture by SEM micrographs [36].

3.2. CF absorption capacity

Cellulose fibre (CF) exhibited a high-water absorption capacity, attributed to its molecular structure, which contains hydroxyl groups (-OH) that form hydrogen bonds with water molecules [37]. The absorption process followed a progressive pattern (Fig. 4), starting with a rapid initial gain, reaching approximately 245% after 20 minutes. This was followed by a more moderate increase between 20 and 12 hours, reaching around 265%. Beyond this point, absorption stabilised near 270%, indicating that the fibres had reached saturation.

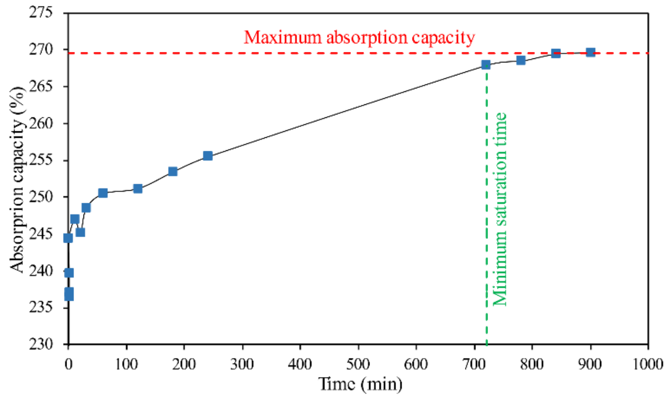

Fig. 4: Water absorption capacity rate of CF.

Based on this behaviour, a minimum pre-saturation time of 12 hours was established to ensure that the CF no longer absorbs mixing water, allowing it to function solely as an internal curing agent without altering the water-to-cement ratio. CF was saturated in the mixing water to control the wetting condition and to facilitate the mixing process.

3.3. Rheological properties and compressive strength of the matrix with CF

Based on the previously established pre-saturation time, the CF was saturated in the mixing water for 12 hours. For matrix evaluation, saturation was carried out using the total mixing water. The mixing process began with all cementitious material and water blended at low speed for 120 seconds. After a 15 to 30-second pause, the remaining water was added while manually scraping the mixer walls. Mixing was then resumed at medium speed for a further 3 minutes.

The rheology performance of the cementitious matrix containing varying CF dosages (3.86, 5.79 and 7.73 kg/m³) was assessed in terms of flowability (%) and APT (mm) (Figures 5a and 5b). An overall improvement in flowability was observed with the addition of CF, reaching 142% for 3.86 kg/m³, 109.7% for 5.79 kg/m³, and 127.5% for 7.73 kg/m³, compared to the control mixture. This enhancement is attributed to the ability of the CF to act as bridges between particles, facilitating improved distribution and reducing localised friction. At lower dosages, CF appear to contribute to lubrication and promote better particle dispersion, increasing fluidity. However, at higher dosages, a slight reduction in flowability was observed, likely due to fibre entanglement and increased interparticle interactions, which raise local viscosity and restrict particle movement [38]. Despite this, the flowability remained similar to or better than the control mixture.

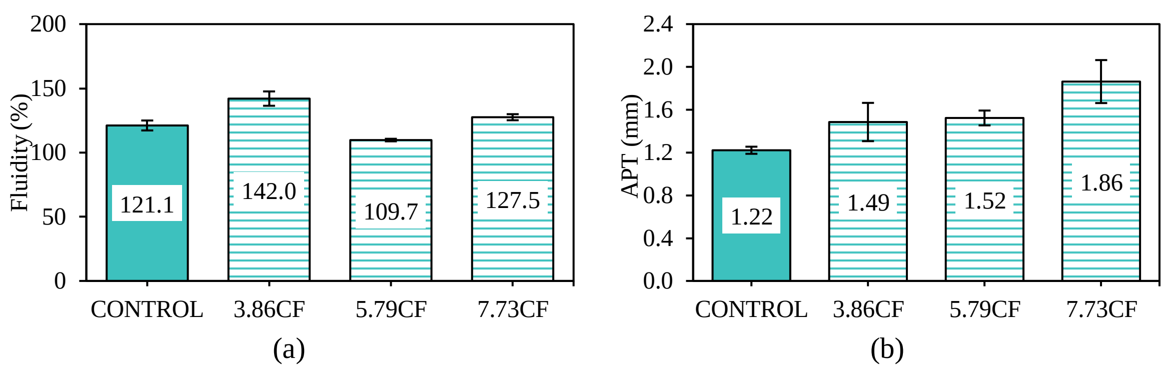

Fig. 5: (a) Fluidity of the matrix containing CF, (b) APT of the matrix containing CF.

APT also increased with across all fibre dosages. The control matrix exhibited an APT of 1.22 mm, while mixes with CF reached values of 1.49 mm (3.86 kg/m³), 1.52 mm (5.79 kg/m³), and 1.86 mm (7.73 kg/m³). This suggests that fully saturated fibres no longer absorb water from the matrix, allowing free water to remain available for cement hydration and promoting a more cohesive matrix around the fibres. At higher dosages, however, fibre stiffness may hinder matrix dispersion, potentially leading to localised paste accumulation and uneven distribution of cement particles.

The compressive strength of the matrices with CF was also evaluated (Fig. 6). At 7 days, a slight reduction in strength was observed compared to the control (58.4 MPa), with results ranging from 48.8 MPa (3.86 kg/m³) to 59.1 MPa (7.73 kg/m³). This reduction could be associated with a delayed early hydration caused by the presence of saturated CF, which, while not absorbing water during mixing, may still influence the rate of hydration reactions and nucleation [25]. However, at 28 days, most samples with CF exhibited improved strength. Notably, the sample with 3.86 kg/m³ CF achieved 67.9 MPa, representing an 11% increase over the control (61.1 MPa). These results confirm that CF does not negatively impact long-term strength and, at specific dosages, can enhance it. This improvement supports the role of CF as internal curing, gradually releasing retained water and facilitating continued hydration and microstructural development.

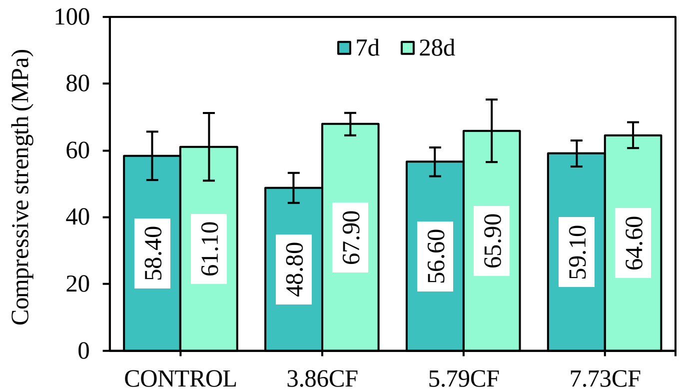

Fig. 6: Compressive strength of the matrix containing CF.

3.4. Validation on pervious concrete with CF

Following the evaluation of the cementitious matrix, the permeability and mechanical properties of pervious concrete incorporating saturated CF were assessed. As shown in Figure 7a, CF incorporation enhanced permeability, yielding values of 18.6, 22.2 and 20.2 mm/s for 3.86, 5.79 and 7.73 kg/m³ CF, respectively, all higher than the control. The highest value, observed at 5.79 kg/m³, represented a 32.93 % increase, while 3.86 and 7.73 kg/m³ yielded improvements of 11.38 % and 20.96 %, respectively. This behaviour is likely attributed to the formation of a thicker and more uniform matrix coating around the aggregates, which improves pore-structure interconnectivity. At higher CF dosages, a slight reduction in permeability was observed, possibly due to fibre entanglement and mixture heterogeneity. Nonetheless, the continuous matrix coating around aggregates maintained permeability values above that of the control.

Figure 7b illustrates that CF addition resulted in a slight increase in compressive strength at early ages, although the long-term effect was minimal. At 7 days, strength improvements were associated with enhanced matrix cohesion provided by fibres. However, by 28 days, the influence diminished, suggesting that CF contributes more to early-stage matrix integrity rather than acting as a long-term reinforcement in pervious concrete.

A similar pattern was observed for flexural strength (Fig. 7c) and splitting tensile strength (Fig. 7d). At 7 days, flexural strength reached 2.93 MPa for the 7.73 kg/m³ CF mix, while other dosages showed more modest gains. However, at 28 days, the flexural strength decreased by up to 19% compared to the control. Splitting tensile strength increased by up to 36% at 7 days, yet values at 28 days were generally similar to the control, except for the 3.86 kg/m³mix, which still showed a 7.69% improvement.

These results suggest that saturated CF enhances the stability and cohesion of the fresh cementitious matrix, especially during the early stages of strength development. However, as the matrix matures and gains intrinsic strength, the influence of CF becomes less significant, and in some cases may slightly reduce strength due to poor fibre-matrix bonding or excessive thickening of the APT, which can alter the pore structure and reduce mechanical efficiency.

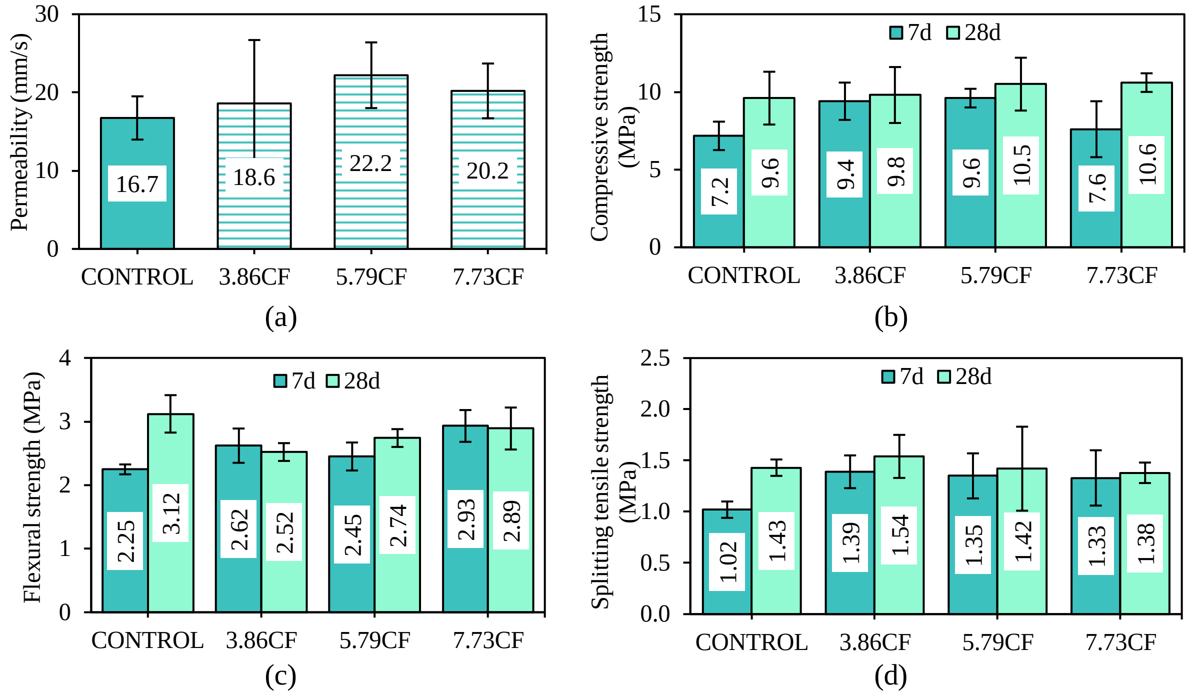

Fig. 7: Properties of the pervious concrete containing CF, (a) permeability, (b) compressive strength, (c) flexural strength, and (d) splitting tensile strength.

Further insights were obtained by examining the failure patterns of the pervious concrete specimens (Fig. 8). In the control mixture, failure occurred in a brittle manner, with clear separation of the fragments and pronounced cracking, indicative of weak bonding between the matrix and aggregates. In contrast, specimens with CF exhibited more controlled crack propagation and retained structural integrity after failure, with reduced fragment separation. The addition of CF appeared to enhance the bond between the matrix and the aggregates, limiting crack spread and improving post-fracture behaviour. These observations suggest that CF contributes to greater ductility and residual load-bearing capacity, providing structural benefits beyond initial cracking.

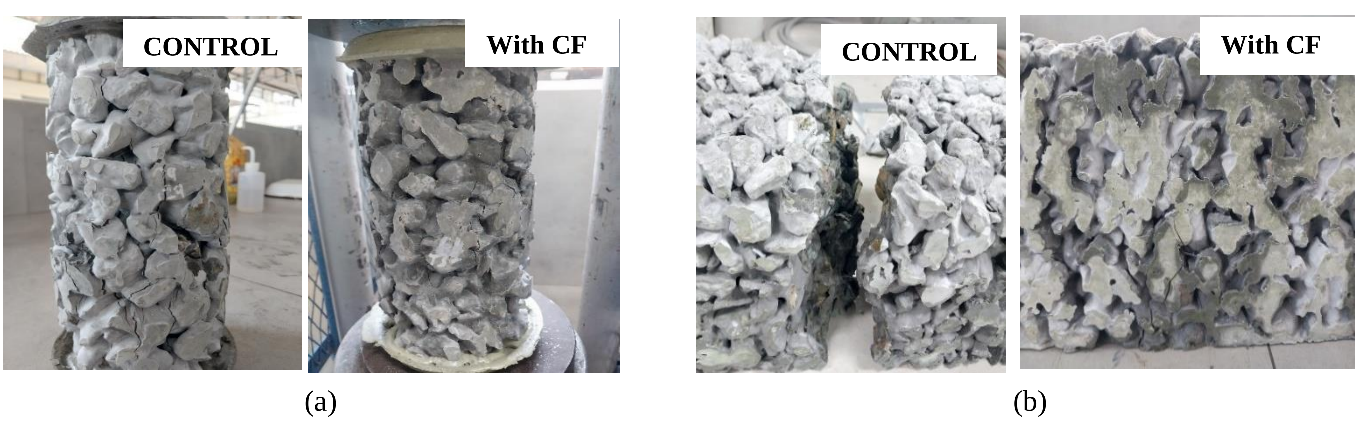

Fig. 8: (a) Typical failure pattern observed in pervious concrete in (a) compressive strength and, (b) flexural strength.

4. Conclusion

This study proposed and validated a straightforward methodology for incorporating recycled cement sacks as cellulose pulp into pervious concrete. Key stages of the process were evaluated, including fibre extraction, pre-saturation, and incorporation into the mixture, as well as their effects on rheological behaviour, mechanical performance, and permeability.

1. The methodology enabled the effective transformation of waste cement sacks into cellulose fibres suitable for direct incorporation into the cementitious matrix, without requiring advanced or energy-intensive processing.
2. At lower dosages, saturated CF improved the flowability of the matrix by promoting particle dispersion and lubrication. All CF dosages increased the average paste thickness (APT), which contributed to a more uniform coating around aggregates and improved matrix distribution. However, excessive fibre content slightly reduced workability due to the fibre entanglement and increased internal friction.
3. Saturation CF ensured preservation and enhancement of permeability in pervious concrete. All dosages showed improvements, with a peak increase of 32.93% at 5.79 kg/m³. attributed to a more cohesive matrix and improved aggregate coating that maintained or enhanced pore connectivity.
4. The saturated CF delayed early hydration, causing a slight reduction in compressive strength at 7 days. However, at 28 days, the mix with 3.86 kg/m³ CF exceeded the strength of the control, confirming the beneficial effect of internal curing. The pre-saturated CF acted as internal reservoirs, gradually releasing moisture during curing rather than absorbing it during mixing. This gradual release supported long-term hydration and microstructural development. While mechanical strength improvements were limited, early-age gains were noted in both flexural and tensile strength, with diminished impact at later ages.

As a general conclusion, the use of CF fibres derived from cement sacks presents a practical and sustainable approach for enhancing the cohesion and permeability of pervious concrete. Future research could explore their effect on other properties, such as durability and resistance to environmental degradation, to further support their use in sustainable construction applications.

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